

# **USE OF COAL DRYING TO REDUCE WATER CONSUMED IN PULVERIZED COAL POWER PLANTS**

**QUARTERLY REPORT FOR THE PERIOD  
January 1, 2005 to March 31, 2005**

by

Edward Levy  
Nenad Sarunac  
Harun Bilirgen  
Wei Zhang

Report Issued April 2005

DOE Award Number DE-FC26-03NT41729

Energy Research Center  
Lehigh University  
117 ATLSS Drive  
Bethlehem, PA 18015

## **DISCLAIMER**

“This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.”

## **ABSTRACT**

This is the ninth Quarterly Report for this project. The background and technical justification for the project are described, including potential benefits of reducing fuel moisture using power plant waste heat, prior to firing the coal in a pulverized coal boiler.

During this last Quarter, comparative analyses were performed for lignite and PRB coals to determine how unit performance varies with coal product moisture. Results are given showing how the coal product moisture level and coal rank affect parameters such as boiler efficiency, station service power needed for fans and pulverizers and net unit heat rate. Results are also given for the effects of coal drying on cooling tower makeup water and comparisons are made between makeup water savings for various times of the year.

## TABLE OF CONTENTS

|  | <u>Page</u> |
|--|-------------|
| INTRODUCTION   | 1           |
| Background   | 1           |
| Previous Work  | 3           |
| This Investigation   | 3           |
| Task 1: Fabricate and Instrument Equipment   | 4           |
| Task 2: Perform Drying Experiments   | 5           |
| Task 3: Develop Drying Models and Compare to Experimental Data                         | 5           |
| Task 4: Drying System Design   | 5           |
| Task 5: Analysis of Impacts on Unit Performance and Cost of Energy                     | 5           |
| EXECUTIVE SUMMARY  | 6           |
| Background   | 6           |
| Results  | 6           |
| DRYING SYSTEM DESIGN AND ANALYSIS OF IMPACTS ON UNIT<br>PERFORMANCE AND COST OF ENERGY | 7           |
| Background   | 7           |
| Results  | 8           |
| Comparison Between Lignite and PRB Coals   | 8           |
| Reduction of Cooling Tower Makeup Water  | 14          |
| CONCLUSIONS  | 19          |
| PLANS FOR NEXT QUARTER   | 19          |
| NOMENCLATURE   | 20          |
| REFERENCES   | 21          |

## LIST OF FIGURES

| <u>Figure</u> |   | <u>Page</u> |
|---------------|---|-------------|
| 1             | Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 1)  | 2           |
| 2             | Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 2)  | 2           |
| 3             | Improvement in Net Unit Heat Rate Versus Reduction in Coal Moisture Content                                       | 4           |
| 4             | Effect of Coal Moisture Content and Coal Type on Mass Ratio of Flue Gas to Coal Flow Rates                        | 9           |
| 5             | Effect of Coal Moisture and Coal Type on Boiler Efficiency  | 10          |
| 6             | Effect of Coal Moisture and Coal Type on Net Unit Heat Rate   | 10          |
| 7             | Effect of Coal Moisture and Coal Type on Flue Gas Flow Rate at ID Fan Inlet and Flow Rate of Inlet Combustion Air | 11          |
| 8             | Effect of Coal Moisture and Coal Type on Flue Gas Temperature at ID Fan Inlet                                     | 11          |
| 9             | Effect of Coal Moisture and Coal Type on FD Fan Power   | 12          |
| 10            | Effect of Coal Moisture and Coal Type on ID Fan Power   | 13          |
| 11            | Effect of Coal Moisture and Coal Type on Coal Feed Rate   | 13          |
| 12            | Effect of Coal Moisture and Coal Type on Mill Power   | 14          |
| 13            | Ratio of Heat Rejected by Cooling Tower to Heat Rejected by Steam Condenser                                       | 15          |
| 14            | Reduction in Cooling Tower Water Evaporation Loss   | 16          |
| 15            | Variation of Cooling Tower Water Evaporation Rate with Season of Year   | 16          |
| 16            | Effect of Time of Year on Cooling Tower Evaporation Rate. Drying System D.  | 17          |

## **LIST OF FIGURES *(continued)***

| <u>Figure</u> |   | <u>Page</u> |
|---------------|---|-------------|
| 17            | Effect of Coal Product Moisture and Time of Year on Reduction of Cooling Tower Makeup Water. Drying System D. | 17          |
| 18            | Effect of Time of Year on Cooling Tower Evaporation Rate. Drying System B.                                    | 18          |
| 19            | Effect of Coal Product Moisture and Time of Year on Reduction of Cooling Tower Makeup Water. Drying System B. | 18          |

## LIST OF TABLES

| <u>Table</u> |   | <u>Page</u> |
|--------------|---|-------------|
| 1            | Ultimate Analyses – Comparison of Lignite and PRB Coals | 8           |

## **INTRODUCTION**

### **Background**

Low rank fuels such as subbituminous coals and lignites contain significant amounts of moisture compared to higher rank coals. Typically, the moisture content of subbituminous coals ranges from 15 to 30 percent, while that for lignites is between 25 and 40 percent, where both are expressed on a wet coal basis.

High fuel moisture has several adverse impacts on the operation of a pulverized coal generating unit. High fuel moisture results in fuel handling problems, and it affects heat rate, mass rate (tonnage) of emissions, and the consumption of water needed for evaporative cooling.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. In particular, the project involves use of power plant waste heat to partially dry the coal before it is fed to the pulverizers. Done in a proper way, coal drying will reduce cooling tower makeup water requirements and also provide heat rate and emissions benefits.

The technology addressed in this project makes use of the hot circulating cooling water leaving the condenser to heat the air used for drying the coal (Figure 1). The temperature of the circulating water leaving the condenser is usually about 49°C (120°F), and this can be used to produce an air stream at approximately 43°C (110°F). Figure 2 shows a variation of this approach, in which coal drying would be accomplished by both warm air, passing through the dryer, and a flow of hot circulating cooling water, passing through a heat exchanger located in the dryer. Higher temperature drying can be accomplished if hot flue gas from the boiler or extracted steam from the turbine cycle is used to supplement the thermal energy obtained from the circulating cooling water. Various options such as these are being examined in this investigation.



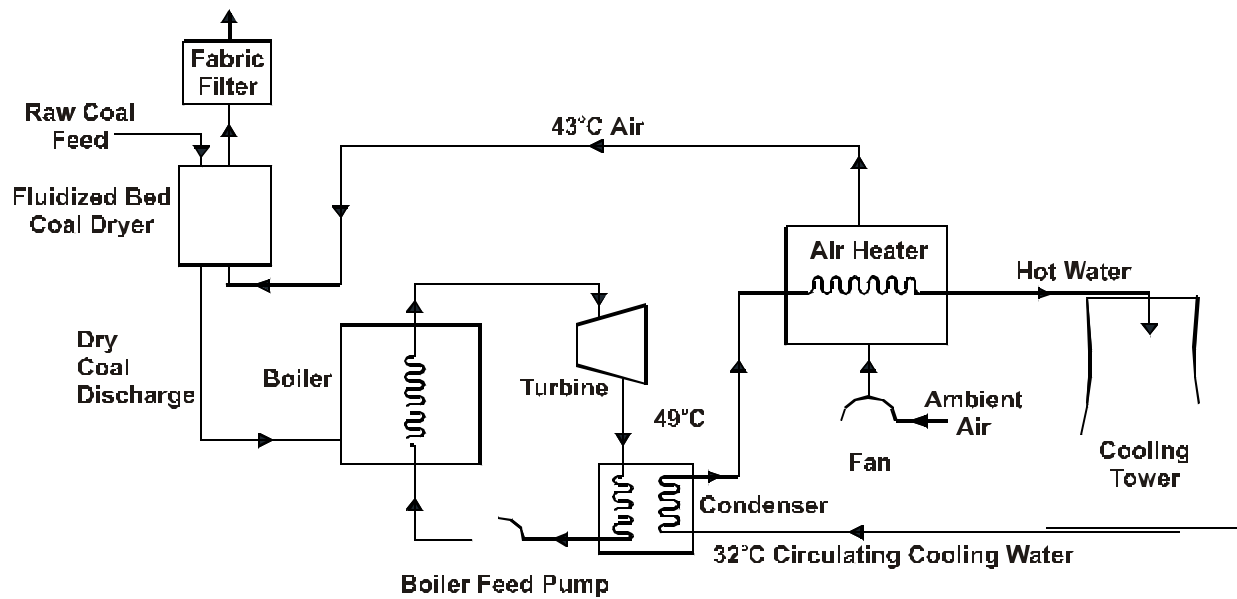


Figure 1: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 1)

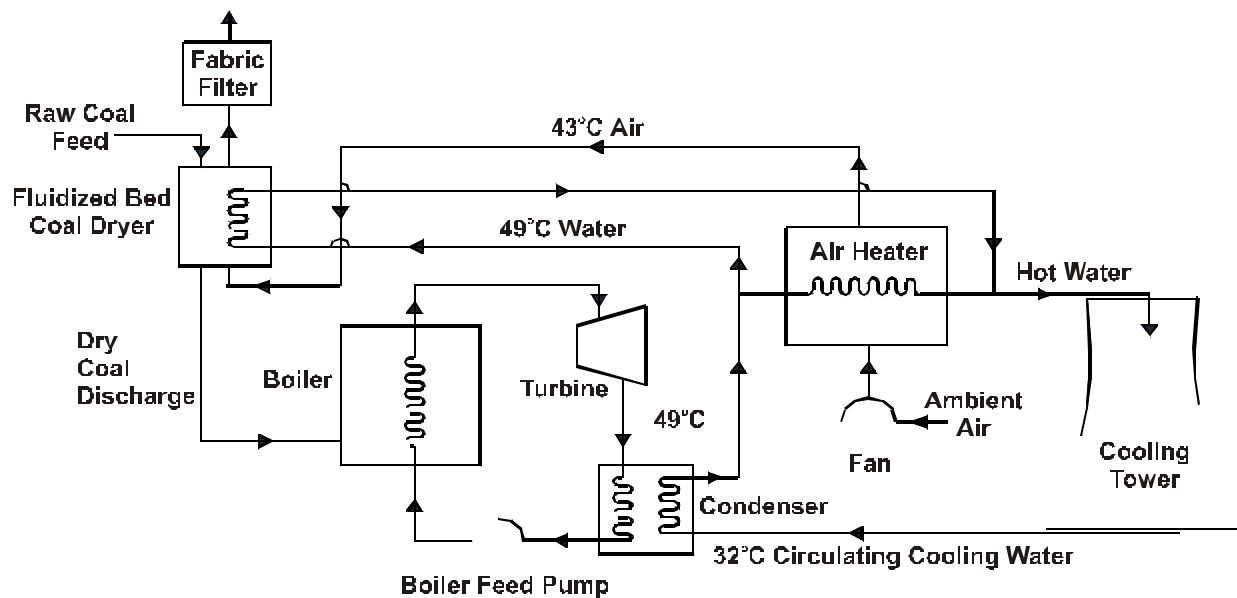


Figure 2: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 2)

## **Previous Work**

Two of the investigators (Levy and Sarunac) have been involved in work with the Great River Energy Corporation on a study of low temperature drying at the Coal Creek Generating Station in Underwood, North Dakota. Coal Creek has two units with total gross generation exceeding 1,100 MW. The units fire a lignite fuel containing approximately 40 percent moisture and 12 percent ash. Both units at Coal Creek are equipped with low NO<sub>x</sub> firing systems and have wet scrubbers and evaporative cooling towers.

A coal test burn was conducted at Coal Creek Unit 2 in October 2001 to determine the effect on unit operations. The lignite was dried for this test by an outdoor stockpile coal drying system. On average, the coal moisture was reduced by 6.1 percent, from 37.5 to 31.4 percent. Analysis of boiler efficiency and net unit heat rate showed that with coal drying, the improvement in boiler efficiency was approximately 2.6 percent, and the improvement in net unit heat rate was 2.7 to 2.8 percent. These results are in close agreement with theoretical predictions (Figure 3). The test data also showed the fuel flow rate was reduced by 10.8 percent and the flue gas flow rate was reduced by 4 percent. The combination of lower coal flow rate and better grindability combined to reduce mill power consumption by approximately 17 percent. Fan power was reduced by 3.8 percent due to lower air and flue gas flow rates. The average reduction in total auxiliary power was approximately 3.8 percent (Ref. 1).

## **This Investigation**

Theoretical analyses and coal test burns performed at a lignite fired power plant show that by reducing the fuel moisture, it is indeed possible to improve boiler performance and unit heat rate, reduce emissions and reduce water consumption by the evaporative cooling tower. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

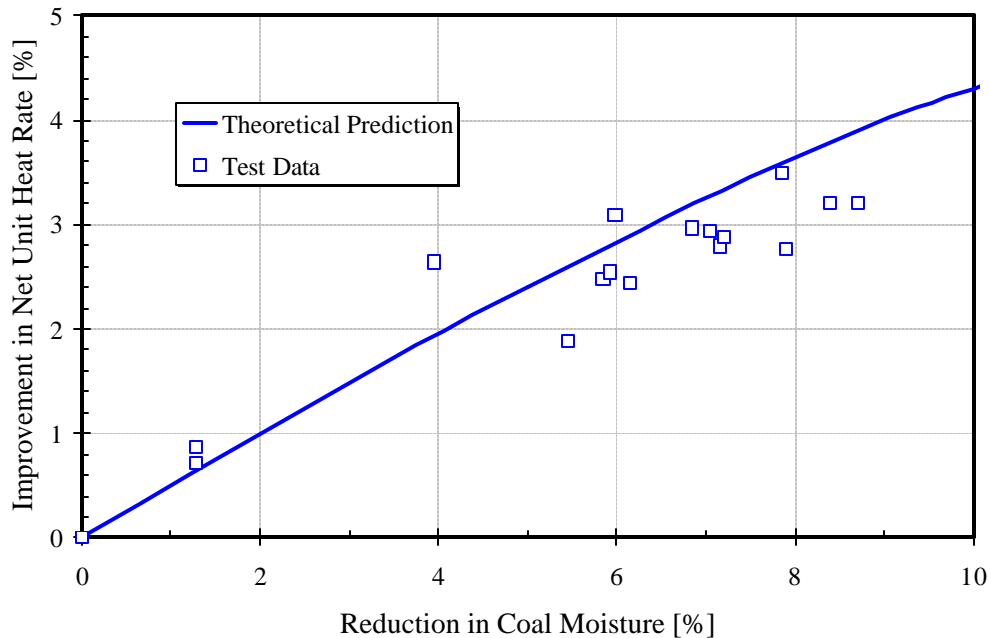


Figure 3: Improvement in Net Unit Heat Rate Versus Reduction in Coal Moisture Content

The present project is evaluating low temperature drying of lignite and Power River Basin (PRB) coal. Drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of the various drying options, along with the development of an optimized system design and recommended operating conditions.

The project is being carried out in five tasks. The original Task Statements included experiments and analyses for both fluidized bed and fixed bed dryers (see previous Quarterly Reports). After the project was started, it became clear there is no advantage to using fixed bed dryers for this application. For this reason, the technical scope was changed in June 2004 to emphasize fluidized bed drying. The Task Statements in this report reflect this change in emphasis.

### **Task 1: Fabricate and Instrument Equipment**

A laboratory scale batch fluidized bed drying system will be designed, fabricated and instrumented in this task. **(Task Complete)**

## **Task 2: Perform Drying Experiments**

The experiments will be carried out while varying superficial air velocity, inlet air temperature and specific humidity, particle size distribution, bed depth, and in-bed heater heat flux. Experiments will be performed with both lignite and PRB coals. **(Task Complete)**

## **Task 3: Develop Drying Models and Compare to Experimental Data**

In this task, the laboratory drying data will be compared to equilibrium and kinetic models to develop models suitable for evaluating tradeoffs between dryer designs. **(Task Complete)**

## **Task 4: Drying System Design**

Using the kinetic data and models from Tasks 2 and 3, dryers will be designed for lignite and PRB coal-fired power plants. Designs will be developed to dry the coal by various amounts. Auxiliary equipment such as fans, water to air heat exchangers, dust collection system and coal crushers will be sized, and installed capital costs and operating costs will be estimated. **(Task Complete)**

## **Task 5: Analysis of Impacts on Unit Performance and Cost of Energy**

Analyses will be performed to estimate the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power, and stack emissions. The cost of energy will be estimated as a function of the reduction in coal moisture content. Cost comparisons will be made between dryer operating conditions (for example, drying temperature and superficial air velocity). **(Task in Progress)**

## **EXECUTIVE SUMMARY**

### **Background**

Low rank fuels such as subbituminous coals and lignites contain relatively large amounts of moisture compared to higher rank coals. High fuel moisture results in fuel handling problems, and it affects station service power, heat rate, and stack gas emissions.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. The project involves use of the hot circulating cooling water leaving the condenser to provide heat needed to partially dry the coal before it is fed to the pulverizers.

Recently completed theoretical analyses and coal test burns performed at a lignite-fired power plant showed that by reducing the fuel moisture, it is possible to reduce water consumption by evaporative cooling towers, improve boiler performance and unit heat rate, and reduce emissions. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

This project is evaluating alternatives for the low temperature drying of lignite and Power River Basin (PRB) coal. Laboratory drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of drying, along with the development of an optimized system design and recommended operating conditions.

### **Results**

Analyses were performed to determine the effects of coal drying on unit performance for identical 570 MW pulverized coal power plants, one firing lignite and the other a PRB coal. In each case, the thermal energy for drying was obtained from power plant waste heat, using drying systems of the same basic design. The results show that while there are small differences due to different coal compositions, the power plant performance impacts due to drying lignite and PRB coals follow the same trends and are very similar in magnitude.

The effects of coal drying on cooling tower makeup water were calculated and found to be a strong function of type of drying system and of ambient temperature and humidity. For the conditions of the analyses and the type of drying system, the reduction in cooling tower makeup water was found to range up to  $2.3 \times 10^6$  liters/day in the winter. Cooling tower makeup water requirements increase with ambient air temperature and humidity and thus are greatest in the summer. The analyses indicate the water savings due to coal drying would be approximately 25 percent larger in the summer than in the winter.

## DRYING SYSTEM DESIGN AND ANALYSIS OF IMPACTS ON UNIT PERFORMANCE AND COST OF ENERGY

### Background

Tasks 4 and 5 involve the design of drying systems for 570 MW lignite and PRB coal-fired power plants, analysis of the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power and stack emissions, and estimation of the cost of energy as a function of reduction in coal moisture content and dryer design. The work in these two tasks is progressing in the following subtasks:

- Subtask 1: Estimate effects of firing dried coal on flow rates of combustion air and flue gas, required feed rate of coal to boiler, mill and fan power, boiler efficiency and unit heat rate. **(Complete)**
- Subtask 2: Estimate required dryer size, flow rates of fluidizing air and amount of in-bed heat transfer as functions of drying temperature and coal product moisture. **(Complete)**
- Subtask 3: Integrate dryer into boiler and turbine cycle and calculate overall impacts on heat rate, evaporative cooling tower makeup water and emissions. **(Complete)**
- Subtask 4: Size remaining components and develop drying system cost estimates. **(Complete)**
- Subtask 5: Perform calculations to select optimal drying system configuration and product coal moisture. **(In Progress)**

The effort during this reporting period was focused on Subtasks 3 and 4. This report describes analyses performed to determine the relative performance impacts of using power plant waste heat to dry lignite and PRB coals. Results are also presented on the impacts of drying on cooling tower makeup water.

## Results

**Comparisons Between Lignite and PRB Coals.** The effect of coal drying on unit performance was analyzed for identical 570 MW pulverized coal power plants, one firing lignite and the other a PRB coal. An inlet lignite moisture content of 38.5 percent (kg H<sub>2</sub>O/kg wet coal) and inlet PRB moisture of 30 percent were used in the calculations along with a flue gas temperature at the economizer outlet of 441°C.

The ultimate analyses of the lignite and PRB used in the analyses are given in Table 1. These show that on a moisture and ash-free (MAF) basis, the PRB has a higher carbon content, lower oxygen content and slightly lower higher heating value than the lignite. The table also gives analyses for the as-received fuels and for lignite and PRB with the same moisture content (20 percent). Figure 4 shows the variations in flue gas to coal flow rate ratio for lignite and PRB as a function of coal moisture. The results in Table 1 and Figure 4 show that, for the same coal moisture, PRB has a larger higher heating value and larger  $M_{fg}/M_{coal}$  ratio than lignite, and this is due to differences between the two fuels in carbon and oxygen content. These differences affect boiler efficiency, fan power and net unit heat rate.

Table 1  
Ultimate Analyses – Comparison of Lignite and PRB Coals

|          | Units | As-Received |        | 20% Fuel Moisture |        |  | MAF     |        |
|----------|-------|-------------|--------|-------------------|--------|--|---------|--------|
|          |       | Lignite     | PRB    | Lignite           | PRB    |  | Lignite | PRB    |
| Carbon   | % wt  | 34.03       | 49.22  | 44.27             | 56.25  |  | 69.17   | 76.05  |
| Hydrogen | % wt  | 2.97        | 3.49   | 3.87              | 3.99   |  | 6.04    | 5.39   |
| Sulfur   | % wt  | 0.51        | 0.35   | 0.67              | 0.40   |  | 1.04    | 0.54   |
| Oxygen   | % wt  | 10.97       | 10.91  | 14.27             | 12.47  |  | 22.29   | 16.86  |
| Nitrogen | % wt  | 0.72        | 0.75   | 0.92              | 0.86   |  | 1.46    | 1.16   |
| Moisture | % wt  | 38.50       | 30.00  | 20.00             | 20.00  |  | 0.00    | 0.00   |
| Ash      | % wt  | 12.30       | 5.28   | 16.00             | 6.30   |  | 0.00    | 0.00   |
| TOTAL    | % wt  | 100.00      | 100.00 | 100.00            | 100.27 |  | 100.00  | 100.00 |
| HHV      | kJ/kg | 14,900      | 19,418 | 19,383            | 22,193 |  | 30,287  | 30,003 |

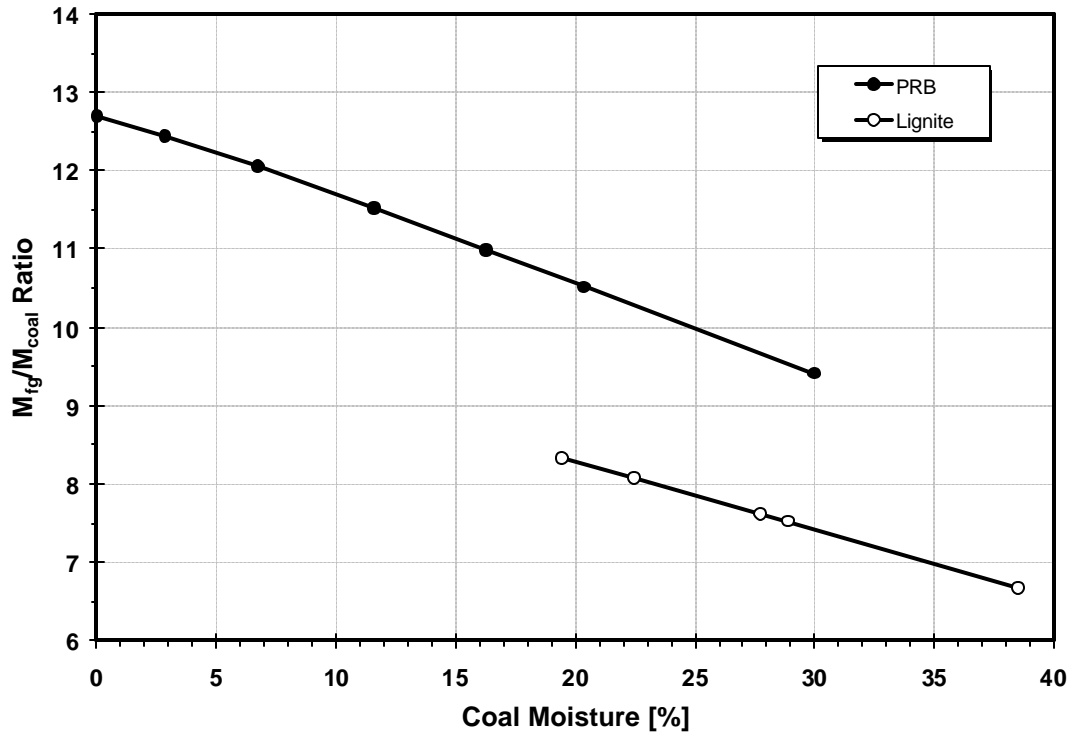


Figure 4: Effect of Coal Moisture Content and Coal Type on Mass Ratio of Flue Gas to Coal Flow Rates

Figure 5, which shows the effect of coal moisture on boiler efficiency, shows the same trends for boiler efficiency for the two coals, but with the PRB having a larger boiler efficiency than the lignite. The percentage increase in boiler efficiency with increased coal drying is roughly the same for both fuels. The PRB calculations were taken all the way to zero percent coal moisture, and the resulting PRB curve indicates the boiler efficiency reaches a maximum and then decreases slightly as the coal moisture approaches zero.

A comparison of the heat rates for the two fuels (Figure 6) shows similar trends, but with the PRB having the lower heat rate.

Figure 7 compares flue gas flow rates at the induced fan inlet and the inlet primary and secondary air flows. This shows that for equal fuel moistures, the PRB requires more combustion air and produces a larger flue gas flow rate. In addition, the flue gas temperature at the ID fan inlet is higher in the PRB case (Figure 8).



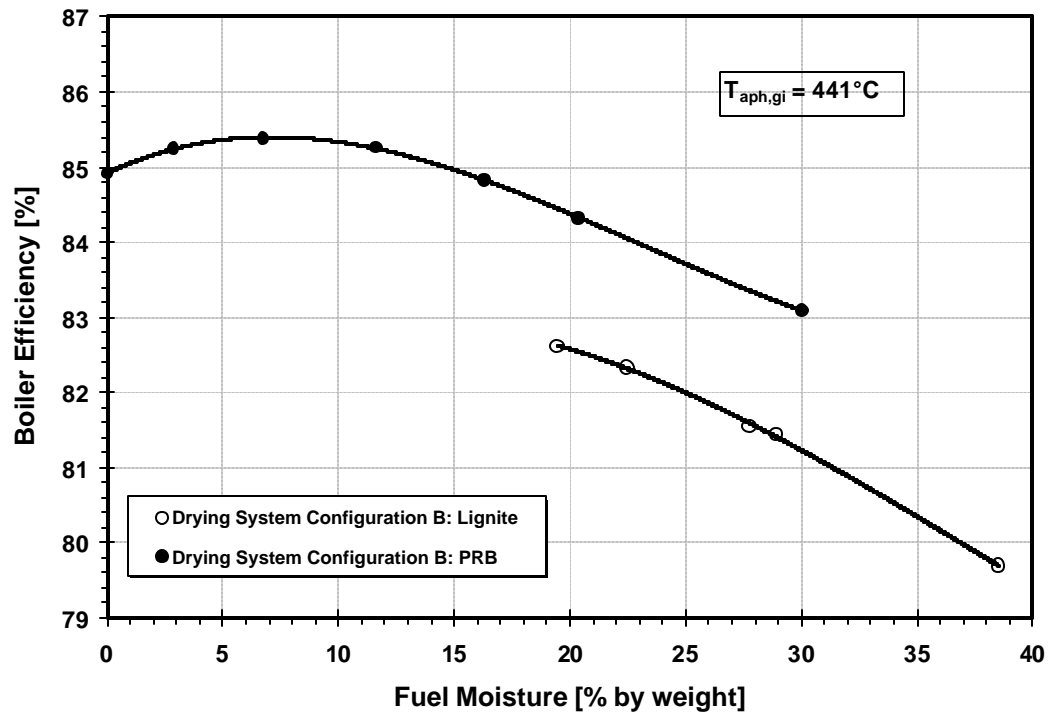


Figure 5: Effect of Coal Moisture and Coal Type on Boiler Efficiency

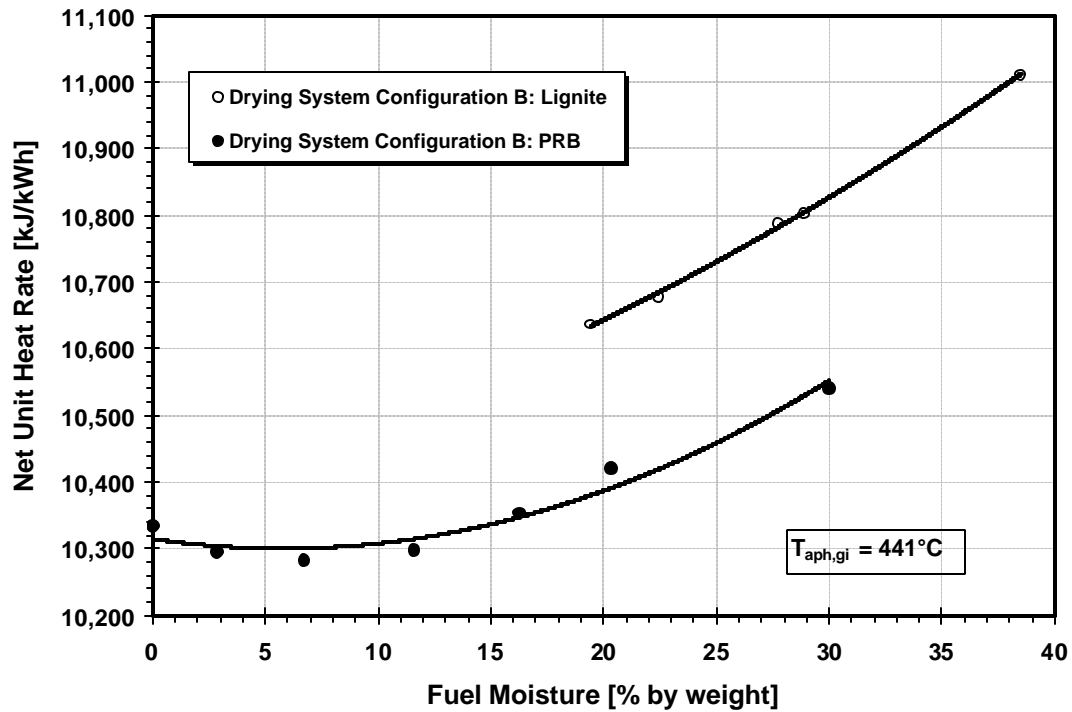


Figure 6: Effect of Coal Moisture and Coal Type on Net Unit Heat Rate

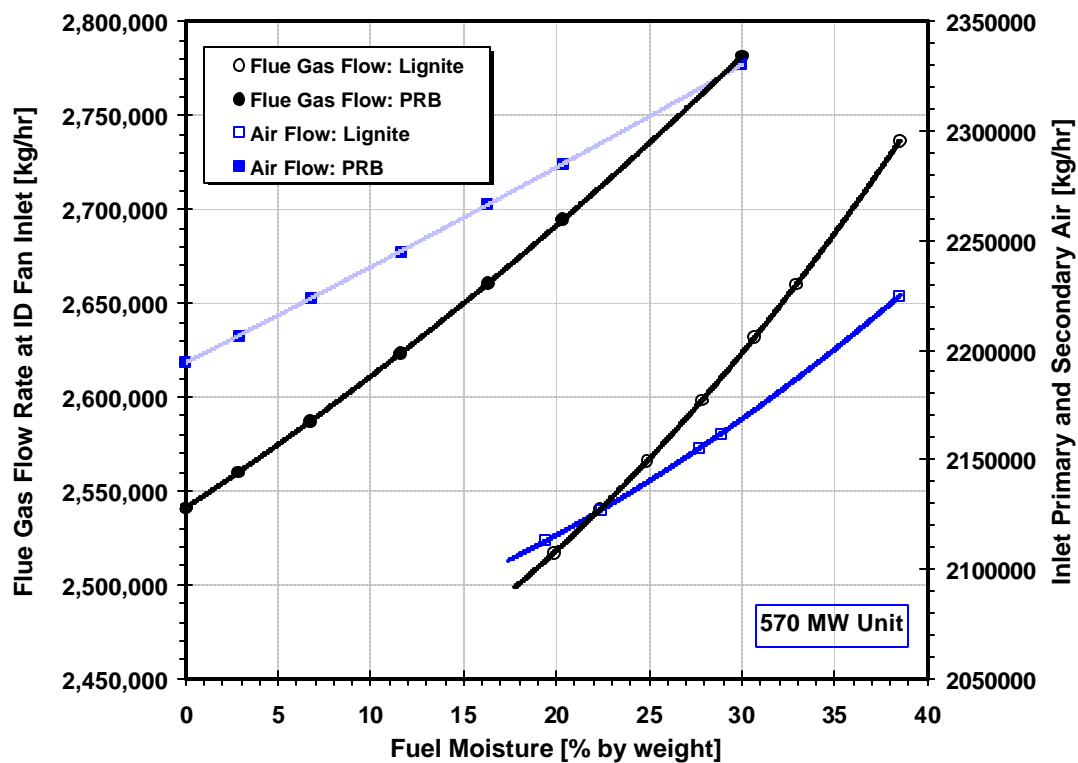


Figure 7: Effect of Coal Moisture and Coal Type on Flue Gas Flow Rate at ID Fan Inlet and Flow Rate of Inlet Combustion Air

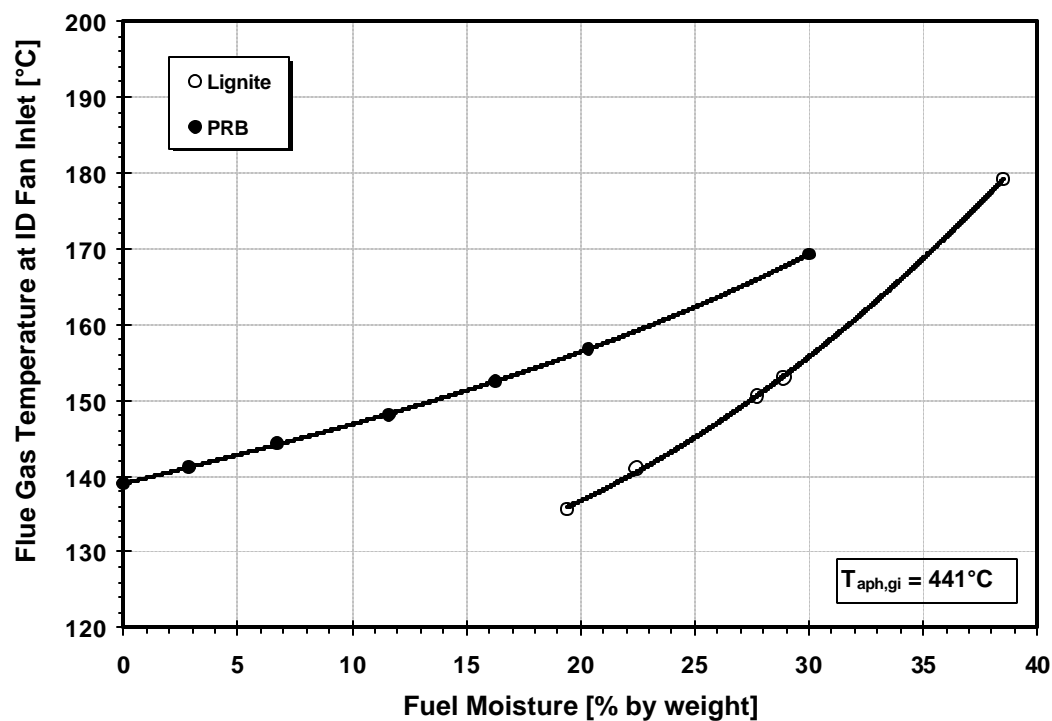


Figure 8: Effect of Coal Moisture and Coal Type on Flue Gas Temperature at ID Fan Inlet

Station service power is also an important parameter. The FD fan power decreases as a result of coal drying and this decrease is proportional to the decrease in heat rate. Both fuels exhibit the same FD power trends (Figure 9). The decrease in ID fan power with decreasing coal moisture (Figure 10) occurs due to the reduction in heat rate and the reduction in flue gas moisture.

Coal flow rate decreases with increasing amounts of coal drying due to less moisture in the fuel and an improved heat rate (Figure 11) and these trends result in a decrease in mill power (Figure 12).

Figures 4 through 12 show that while there are small differences due to different coal compositions, the performance impacts due to drying lignite and PRB coals follow the same trends and are very similar in magnitude.

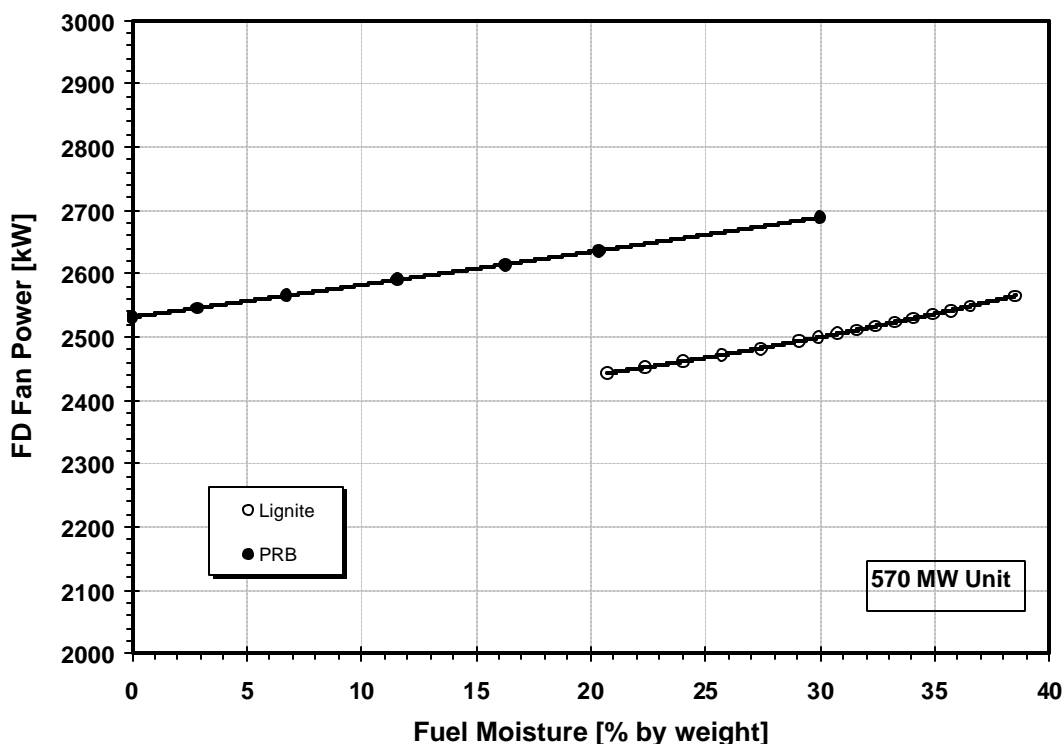


Figure 9: Effect of Coal Moisture and Coal Type on FD Fan Power

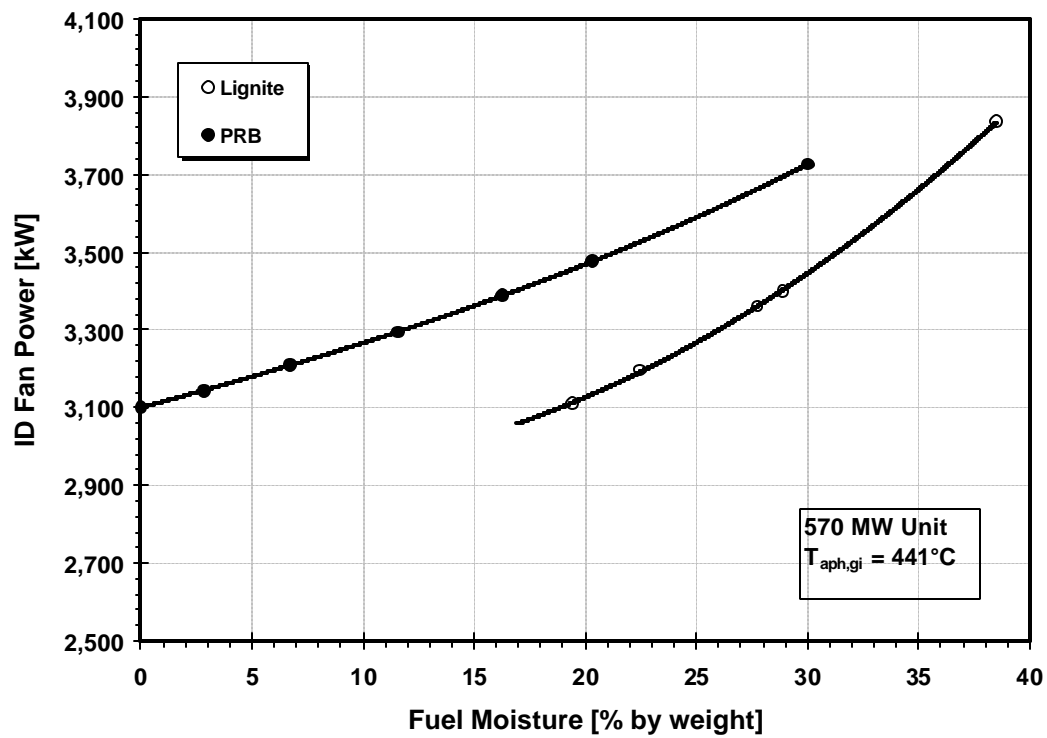


Figure 10: Effect of Coal Moisture and Coal Type on ID Fan Power

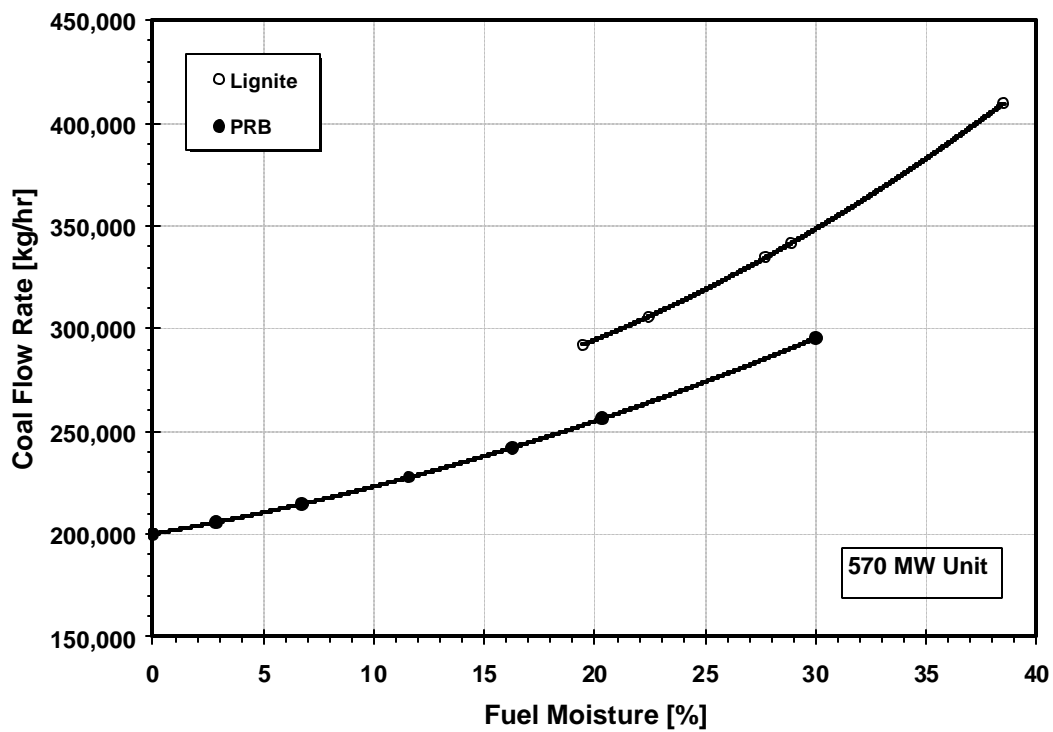


Figure 11: Effect of Coal Moisture and Coal Type on Coal Feed Rate

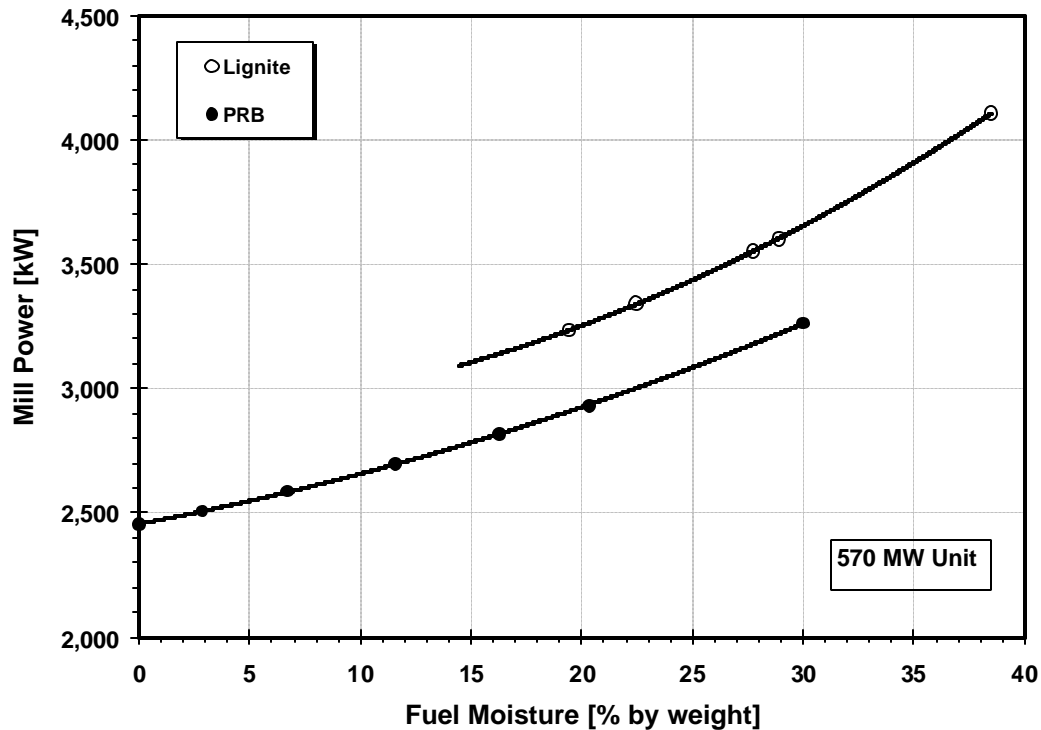


Figure 12: Effect of Coal Moisture and Coal Type on Mill Power

**Reduction of Cooling Tower Makeup Water.** Results presented in the last Quarterly Report compared boiler efficiencies, station service power, and heat rates as functions of lignite coal product moisture for the four drying systems which were considered. Those analyses have now been extended to include estimated impacts of drying on cooling tower makeup water.

The results shown here for cooling tower effects were obtained for the case of an economizer exit gas temperature of 343°C. Four drying systems are included and are referred to here as Systems A, B, C and D.

Figures 13 and 14 show the heat rejected by the cooling tower and the reduction in cooling tower makeup water depend strongly on the type of drying system. For the conditions of these analyses (44°C ambient air temperature and reduction in lignite moisture from 38.5 to 20 percent), the reduction in cooling tower makeup water was found to range up to  $6 \times 10^5$  gallons per day ( $2.3 \times 10^6$  liters/day).

Cooling tower analyses were also performed for Summer and Spring/Fall air temperature and humidity conditions to determine how water savings would vary with time of year. Figure 15 shows seasonal evaporation loss as a function of cooling tower heat rejection. At a given rate of heat rejection, the tower makeup water requirements increase with ambient air temperature and humidity level and are thus are greatest in the Summer. Figure 16 shows how the evaporation loss versus fuel moisture curves depend on season of the year for drying system D. The corresponding reduction in cooling tower makeup water due to drying is shown in Figure 17 for different seasons, and Figures 18 and 19 show the same parameters for drying system B.

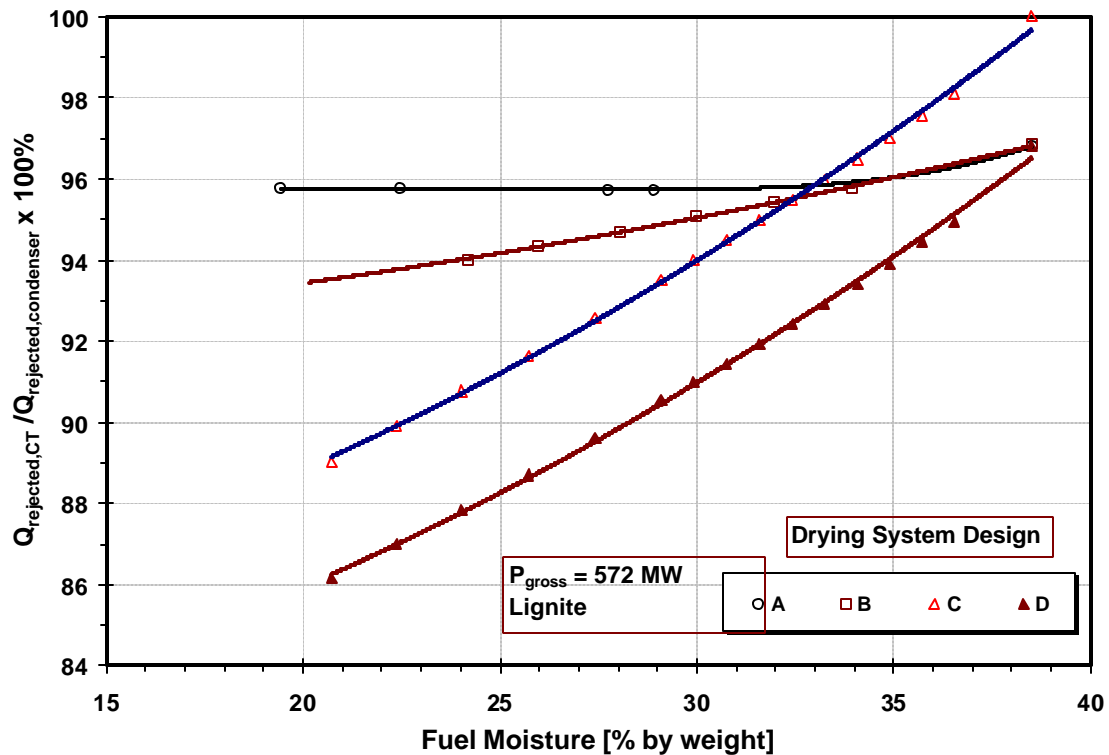


Figure 13: Ratio of Heat Rejected by Cooling Tower to Heat Rejected by Steam Condenser

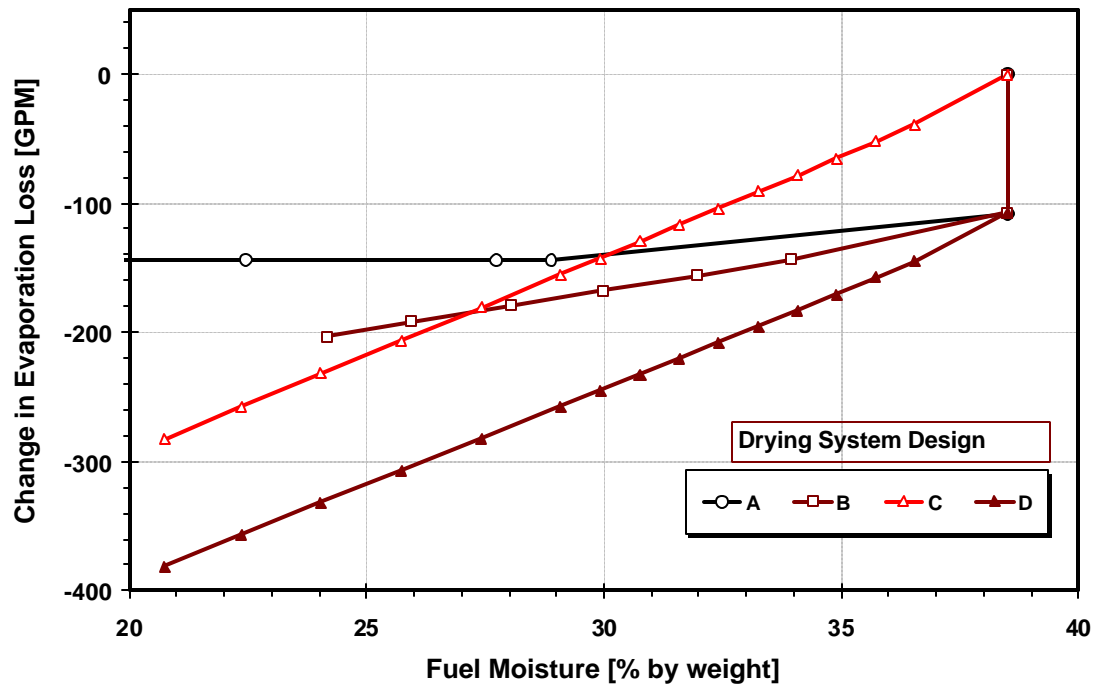


Figure 14: Reduction in Cooling Tower Water Evaporation Loss

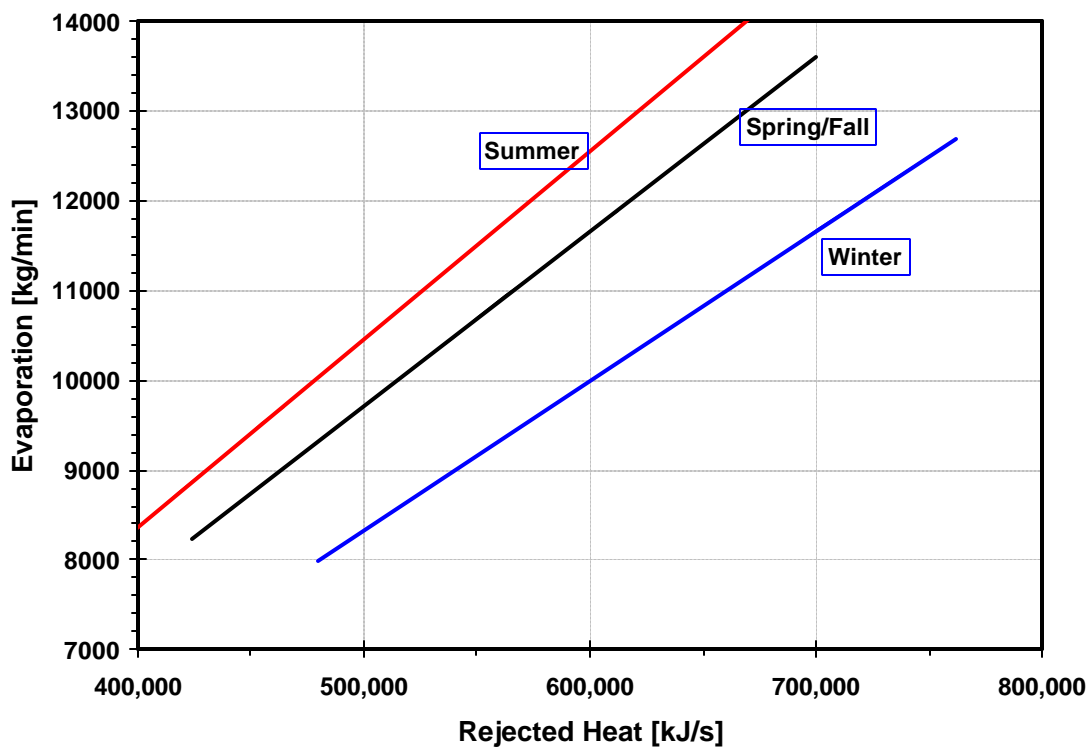


Figure 15: Variation of Cooling Tower Water Evaporation Rate with Season of Year

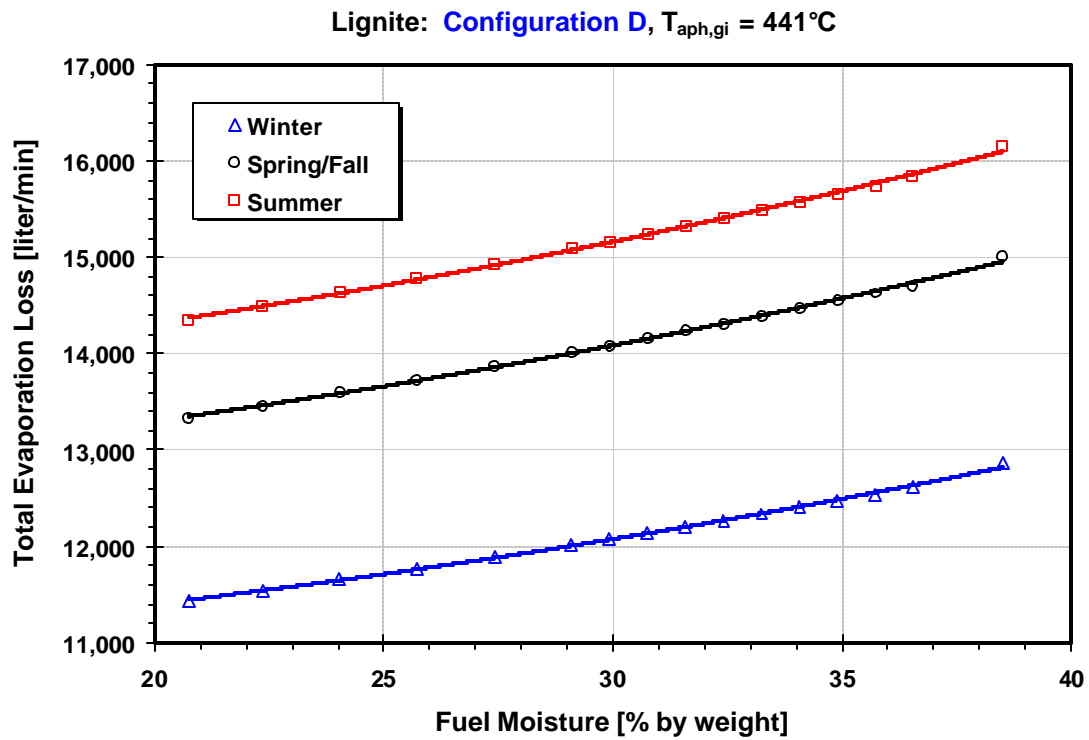


Figure 16: Effect of Time of Year on Cooling Tower Evaporation Rate. Drying System D.

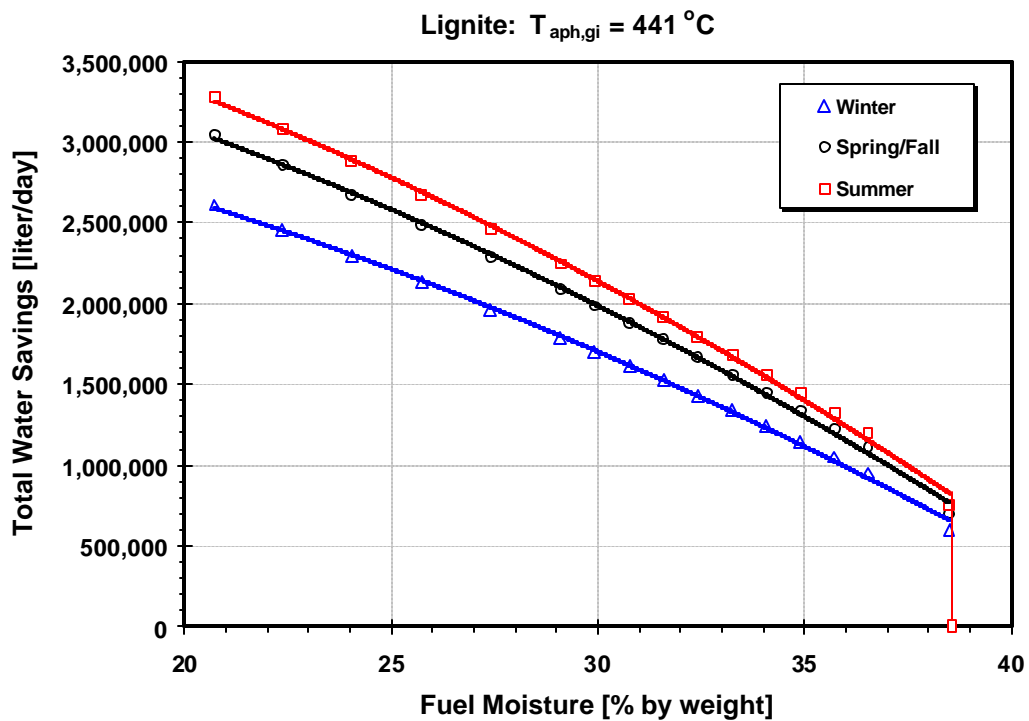


Figure 17: Effect of Coal Product Moisture and Time of Year on Reduction of Cooling Tower Makeup Water. Drying System D.



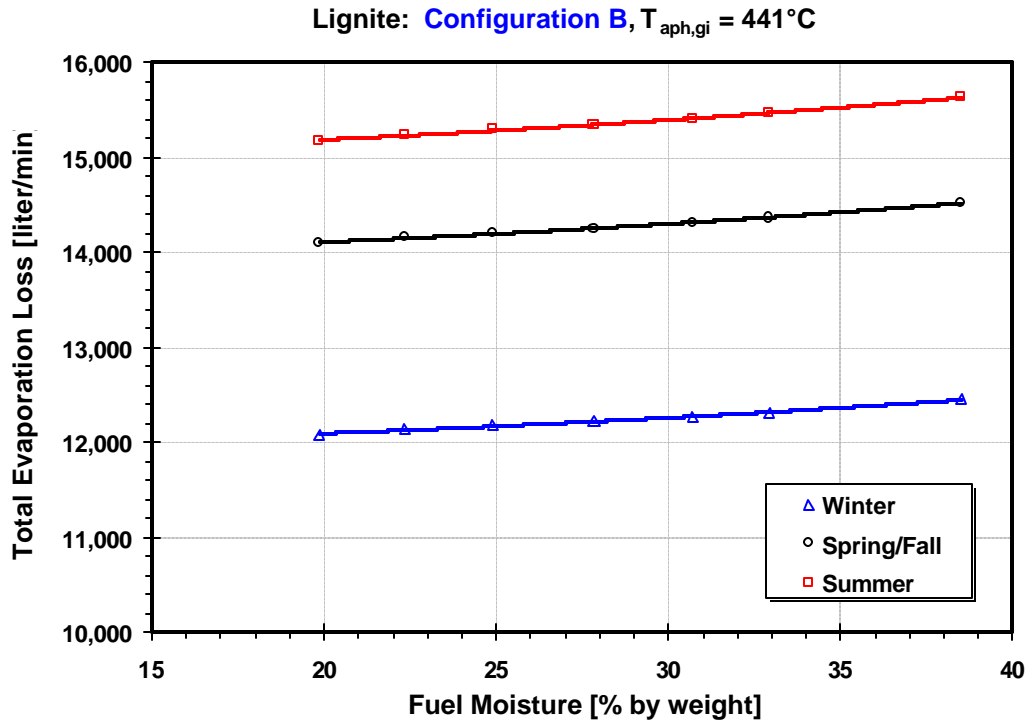


Figure 18: Effect of Time of Year on Cooling Tower Evaporation Rate. Drying System B.

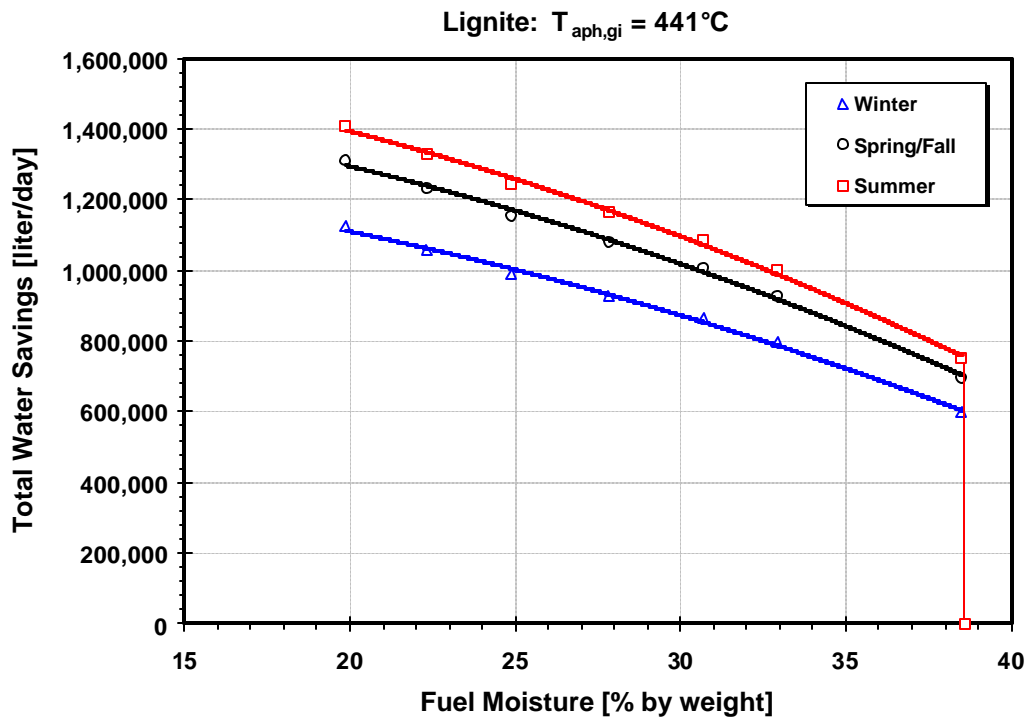


Figure 19: Effect of Coal Product Moisture and Time of Year on Reduction of Cooling Tower Makeup Water. Drying System B.

## **CONCLUSIONS**

Covered in this report are: (1) analyses to determine the relative power plant performance impacts of using power plant waste heat to dry lignite and PRB coals, and (2) analyses to determine the potential water savings due to the reduction in cooling tower makeup water requirements.

Analyses were performed to determine the effects of coal drying on unit performance for identical 570 MW pulverized coal power plants, one firing lignite and the other a PRB coal. In each case, the thermal energy for drying was obtained from power plant waste heat, using drying systems of the same basic design. The results show that while there are small differences due to different coal compositions, the power plant performance impacts due to drying lignite and PRB coals follow the same trends and are very similar in magnitude.

The effects of coal drying on cooling tower makeup water were calculated and found to be a strong function of type of drying system and of ambient temperature and humidity. For the conditions of the analyses and the type of drying system, the reduction in cooling tower makeup water was found to range up to  $2.3 \times 10^6$  liters/day in the winter. Cooling tower makeup water requirements increase with ambient air temperature and humidity and thus are greatest in the summer. The analyses indicate the water savings due to coal drying would be approximately 25 percent larger in the summer than in the winter.

## **PLANS FOR NEXT QUARTER**

The Task 5 analyses on impacts of drying on cost of energy will be completed and cost comparisons will be made between various drying system configurations and operating conditions.

## NOMENCLATURE

|                   |   |
|-------------------|---|
| $A$               | Area  |
| $C$               | Coal Moisture (wet basis)                       |
| $H$               | Bed Depth                                       |
| $M_{\text{air}}$  | Air Flow Rate                                   |
| $M_{\text{coal}}$ | Coal Flow Rate                                  |
| $\Delta P$        | Fan Pressure Rise                               |
| $P_g$             | Gross Electrical Power                          |
| $P_{\text{ss}}$   | Station Service Power                           |
| $P_{\text{net}}$  | Net Electrical Power                            |
| $Q$               | Rate of Heat Transfer                           |
| $T$               | Temperature                                     |
| $U$               | Overall Heat Transfer Coefficient               |
| $\Gamma$          | Coal Moisture (kg H <sub>2</sub> O/kg dry coal) |
| $\phi$            | Relative Humidity                               |
| $\omega$          | Specific Humidity                               |

### Subscripts

- <sub>1</sub> Entering Dryer
- <sub>2</sub> Leaving Dryer

### Abbreviations

|     |                               |
|-----|-------------------------------|
| APH | Air Preheater                 |
| CA  | Combustion Air                |
| FA  | Fluidizing Air                |
| FB  | Fluidized Bed                 |
| FD  | Forced Draft                  |
| gi  | Gas Inlet                     |
| HCW | Hot Circulating Cooling Water |
| ID  | Induced Draft                 |

## REFERENCES

1. Bullinger, C., M. Ness, N. Sarunac, E. K. Levy, "Coal Drying Improves Performance and Reduces Emissions," Presented at the 27<sup>th</sup> International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida, March 4-7, 2002.
2. E. K. Levy et al. "Use of Coal Drying to Reduce Water Consumed in Pulverized Coal Power Plants," DOE Project DE-FC26-03NT41729. Quarterly Report for the Period January 1, 2004 to March 31, 2004.
3. Combustion: Fossil Power Systems, ed. J. Singer 3<sup>rd</sup> Ed. published by Combustion Engineering, Inc. 1981